JGG coil configuration and magnetic field implications

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0.1 Introduction

The Jolly Green Giant (JGG) magnet is used in the MIPP experiment and was previously used in E690 at Fermilab and at BNL. It consists of four 'pancakes' of coils. Each 'pancake is an epoxied assembly. There are two pancakes on top and two below the aperture.

Each pancake has 16 coils inside. Each coil has two turns. All coils in a pancake are operated in series. Sometimes coils short and have to be jumpered out. This document examines issues related to such changes.

0.2 Historical information

It is important to know what currents the JGG coils can be operated at. There is information from Dave Christian on this from E690:

> Here's a summary of how we ran the JGG:
>
> There are 4 coils, 2 above the gap & 2 below. Each coil has resistance 0.220 ohms. At BNL, we operated all 4 coils in parallel, with a total current of 3000 Amps (V=165 Volts). At FNAL, we connected pairs of coils in series, so there were two parallel current paths. We initially ran with a total current of 1500 Amps (V=330 Volts). Near the beginning of the run, we discovered that one coil

had an internal short. We jumpered out the shorted section (in one of the lower coils), reconfigured the series/parallel circuit so that the upper two coils were in series & the lower two coils were in series, & ran with a total current of 1753 Amps (V=373 Volts). The current split 764 Amps in the upper coils & 989 Amps in the lower coils so that the number of Amp-turns was about the same above & below the gap.

In each of these configurations, the central field was approximately 7kG & the field near the pole tips was 8kG.

0.3 The series-parallel configuration

0.3.1 All coils ok

If all four pancakes are run with all coils and they are run in two parallel branches (a and b) with two pancakes in series each (1 and 2) (e.g. both top pancakes in series and both bottom coils in series) then the following equations hold for current, resistance, voltage, and power and B-field in the magnet (let c be the resistance of a single coil):

$$V_0^* = V_a^* = V_b^* = R_0^* \times I_0^* \tag{1}$$

$$I_0^* = 2I_a^* = 2I_b^* = I_a^* + I_b^* \tag{2}$$

$$R_0^* = \frac{R_a^*}{2} = \frac{R_b^*}{2} = 16 \times c \tag{3}$$

$$P_0^* = 2P_a^* = 2P_b^* = P_a^* + P_b^* = R_0^* \times (I_0^*)^2 \tag{4}$$

$$B^* \propto 32 \times I_a^* + 32 \times I_b^* = 32 \times I_0^* \tag{5}$$

The B-field is proportional to the integral over current times coils. If everything is symmetric there are 64 coils each flowing half of I_0. Here we make the assumption that all coils have the same resistance and ignore small deviations that will be important in data analysis.

0.3.2 Some coils jumpered out

Now let's assume that in branch b some number n of the coils is jumpered out. This causes more current to flow through branch b than through branch a. The product of current and number of coils will be the same in each branch. So the field shape will be the same to first order and only the field strength will change to first order.

$$V_0 = V_a = V_b = R_0 \times I_0 \tag{6}$$

$$I_a = \frac{32-n}{64-n} I_0 \tag{7}$$

$$I_b = \frac{32}{64-n} I_0 \tag{8}$$

$$I_0 = I_a + I_b \tag{9}$$

$$R_a = 32 \times c = R_a^* \tag{10}$$

$$R_b = (32-n) \times c = \frac{32-n}{32} R_b^* \tag{11}$$

$$R_0 = \frac{R_a \times R_b}{R_a + R_b} = \frac{32 \times (32-n)}{64-n} c \tag{12}$$

$$P_0 = P_a + P_b \tag{13}$$

$$B \propto 32 I_a + (32-n) I_b = \frac{32 \times (32-n)}{(64-n)} I_0 \times 2 = 64 \times \frac{32-n}{64-n} I_0 \tag{14}$$

In order to get the same B-field strength with n coils missing the current has to be increased by a factor $f = \frac{I_0}{I_0^*}$:

$$32 I_0^* = 64 \times \frac{32-n}{64-n} I_0 \tag{15}$$

$$f = \frac{32 \times (64-n)}{64 \times (32-n)} \tag{16}$$

Now the change in power can be obtained as:

$$I_a = \frac{32-n}{64-n} \times f I_0^* = \frac{1}{2} I_0^* = I_a^* \tag{17}$$

$$\begin{aligned} P_a &= R_a \times I_a^2 \\ &= R_a^* (I_a^*)^2 \\ &= P_a^* \end{aligned} \tag{18}$$

$$\begin{aligned} I_b &= \frac{32}{64-n} \times f I_0^* = \frac{16}{32-n} I_0^* \\ &= \frac{32}{32-n} I_b^* \end{aligned} \tag{19}$$

$$\begin{aligned} P_b &= R_b \times I_b^2 \\ &= \frac{32-n}{32} R_b^* \times \left(\frac{32}{32-n} \times I_b^* \right)^2 \\ &= \frac{32}{32-n} R_b^* (I_b^*)^2 \\ &= \frac{32}{32-n} P_b^* \end{aligned} \tag{20}$$

As expected the power in the coils a is unchanged in order to produce the same B-field with the same set of coils. In the smaller number of coils in branch b the power has increased by the ratio of the number of coils.

0.3.3 MIPP currents

The MIPP experiment was taking data since January 2005 with 6 coils shorted out in the lower bottom pancake. Now four more pancakes have been shorted out. Zip-tracking and parts of commissioning were done without any bad coils.

When the first six coils were jumpered out we did not adjust the current and rather decided to run at a slightly lower field. The current over the last months was $1450A$ nominal, $1435A$ actual: $I_0(n = 6) = 1435A$. If we want to keep the field identical then we will now need a current of

$$\begin{aligned} I_0(n = 10) &= I_0(6)\frac{f(10)}{f(6)} \\ &= 1579A \end{aligned} \tag{21}$$

This total current will split into $643A$ in the top coils and $936A$ in the bottom coils. We are assured that some of the JGG coils have been operated at $989A$. (7 of the 16 coils in one of the pancakes were shorted out then.) Thus it should be no problem to continue data taking with only minimal (few percent) changes in field shape and strength using the remaining 6 coils of the bottom lower pancake.